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Gurosik et al.

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(54) **POWDER METAL DIE FILLING**

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B22F 5/10 (2006.01)
B22F 3/00 (2006.01)
B22F 3/03 (2006.01)

(52) **U.S. Cl.**
CPC . ***B22F 5/10*** (2013.01); ***B22F 3/004*** (2013.01); *B22F 2003/033* (2013.01); *B22F 2998/00* (2013.01)

(58) **Field of Classification Search**
CPC B22F 3/004
See application file for complete search history.

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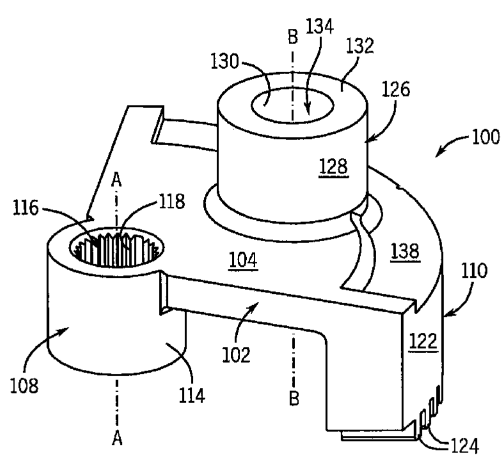
(57) **ABSTRACT**

The disclosed method provides a way to fabricate a powder metal compact implementing a top fill through one or more of the upper tool members. The top fill step allows for pre-compaction chamber, defined at least in part by at least one of the upper tool members, to be filled with a powder metal after the upper tool member is initially lowered, but before compaction of the powder metal. The manner in which the pre-compaction chamber is filled allows for the formation of complex geometries in powder metal compacts that are not obtainable using conventional lower tool powder transfer motions and further minimizes or avoids unacceptable variations in powder fill to final part ratios across the powder metal compact.

15 Claims, 10 Drawing Sheets



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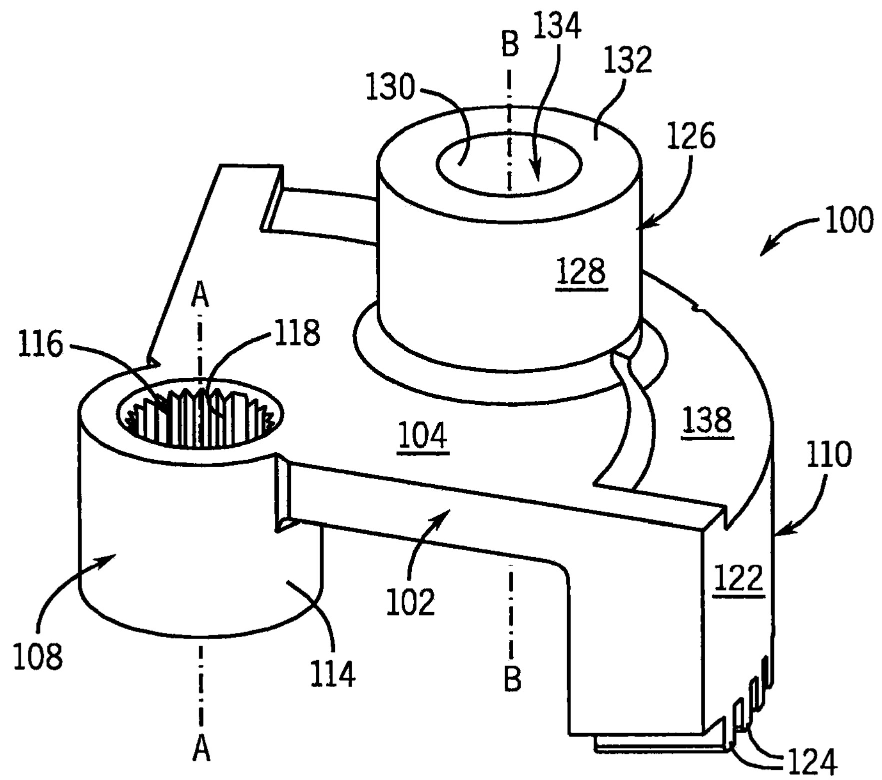
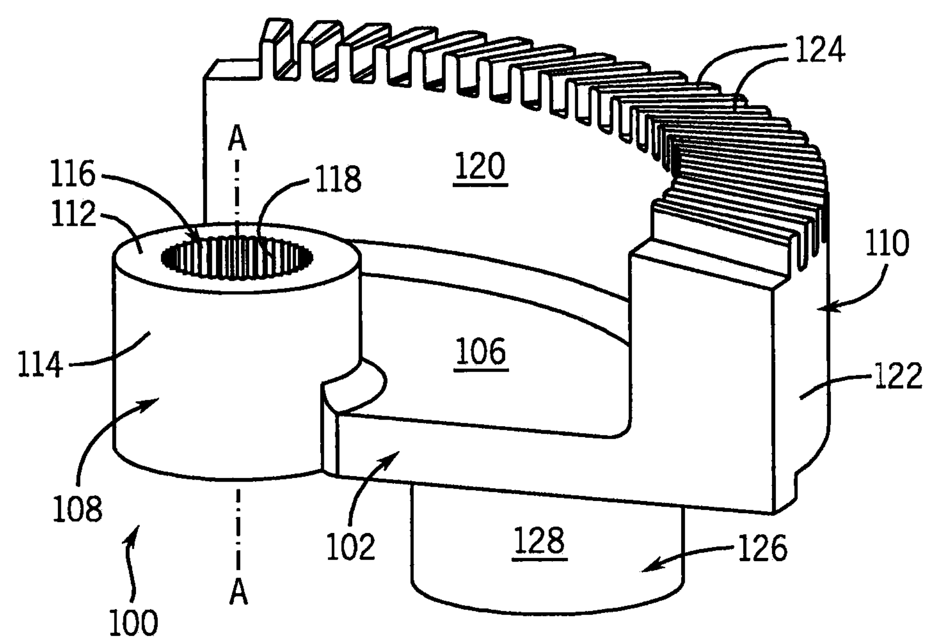


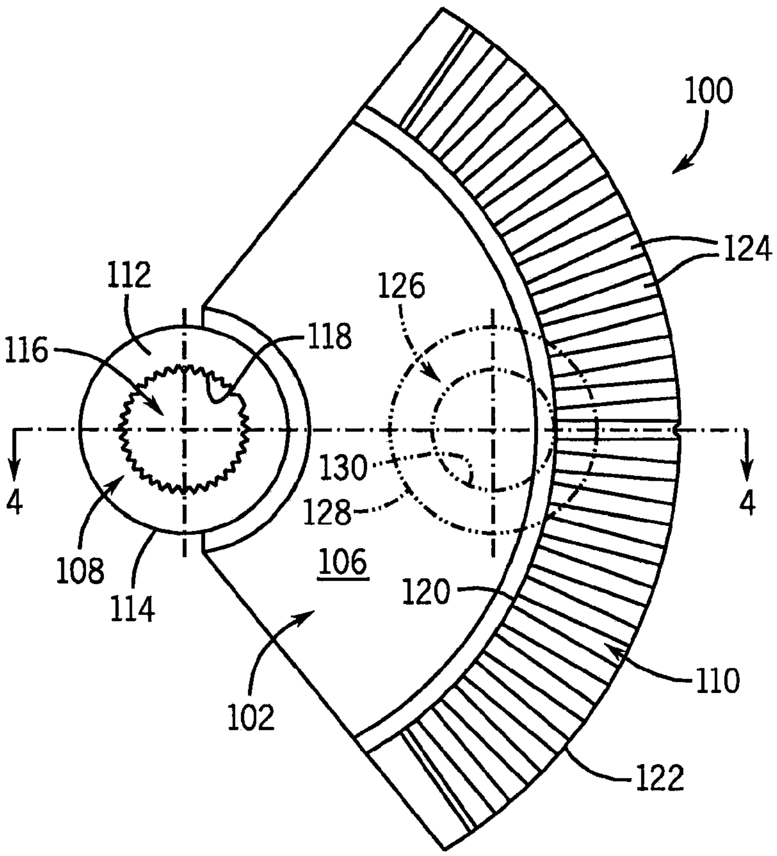
B
134
132
130
126
100
128
A
116
118
138
104
110
122
102
108
114
B
A
124

FIG. 1



124
A
120
116
118
112
110
106
114
122
108
102
128
126
100
A

FIG. 2


100
124
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108
114
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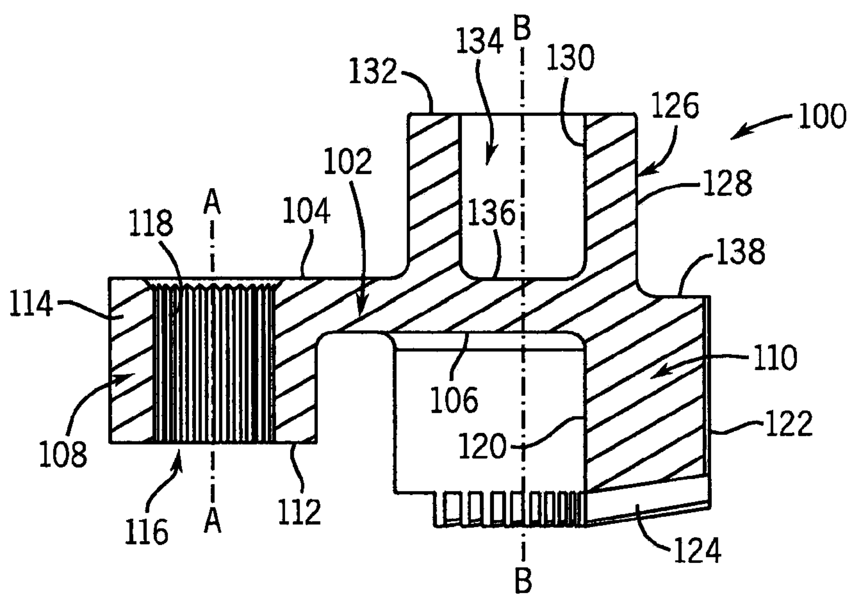
120
110
102
122

FIG. 3


B
134
130
132
126
100
102
128
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104
136
118
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114
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116
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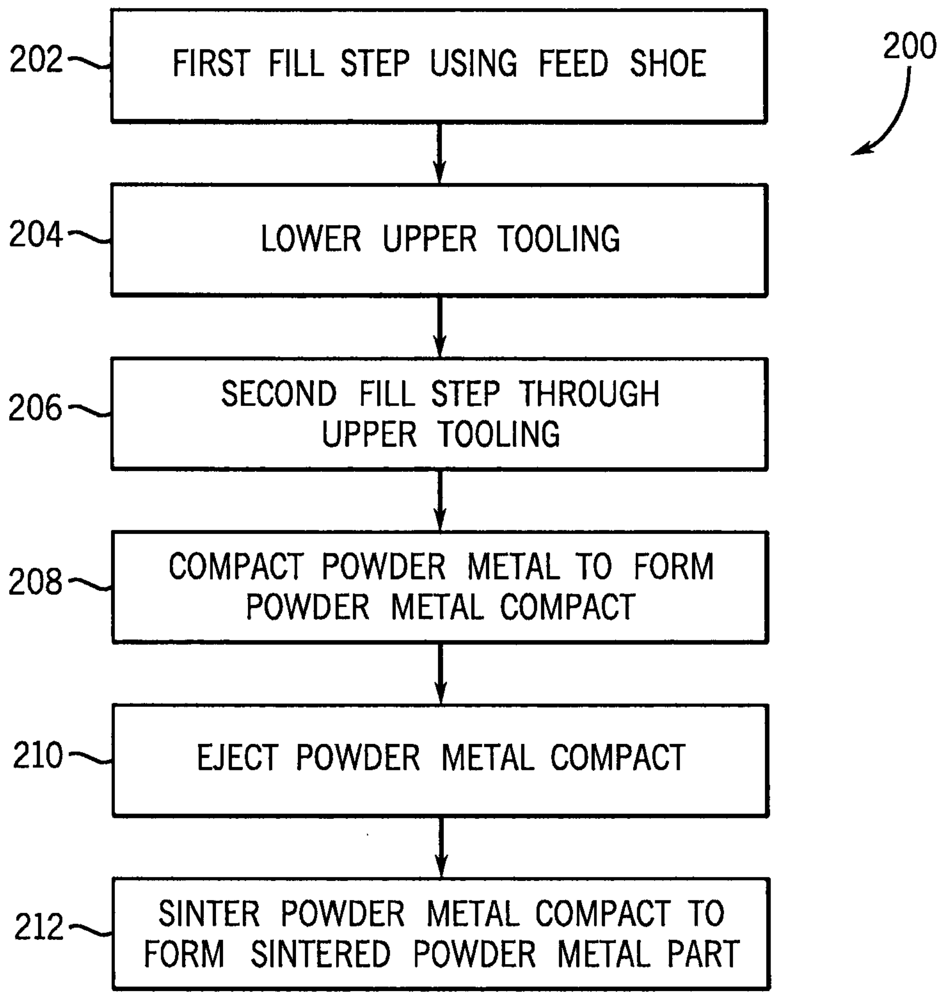
112
124
B

FIG. 4



200
202
FIRST FILL STEP USING FEED SHOE
204
LOWER UPPER TOOLING
206
SECOND FILL STEP THROUGH UPPER TOOLING
208
COMPACT POWDER METAL TO FORM POWDER METAL COMPACT
210
EJECT POWDER METAL COMPACT
212
SINTER POWDER METAL COMPACT TO FORM SINTERED POWDER METAL PART

FIG. 5

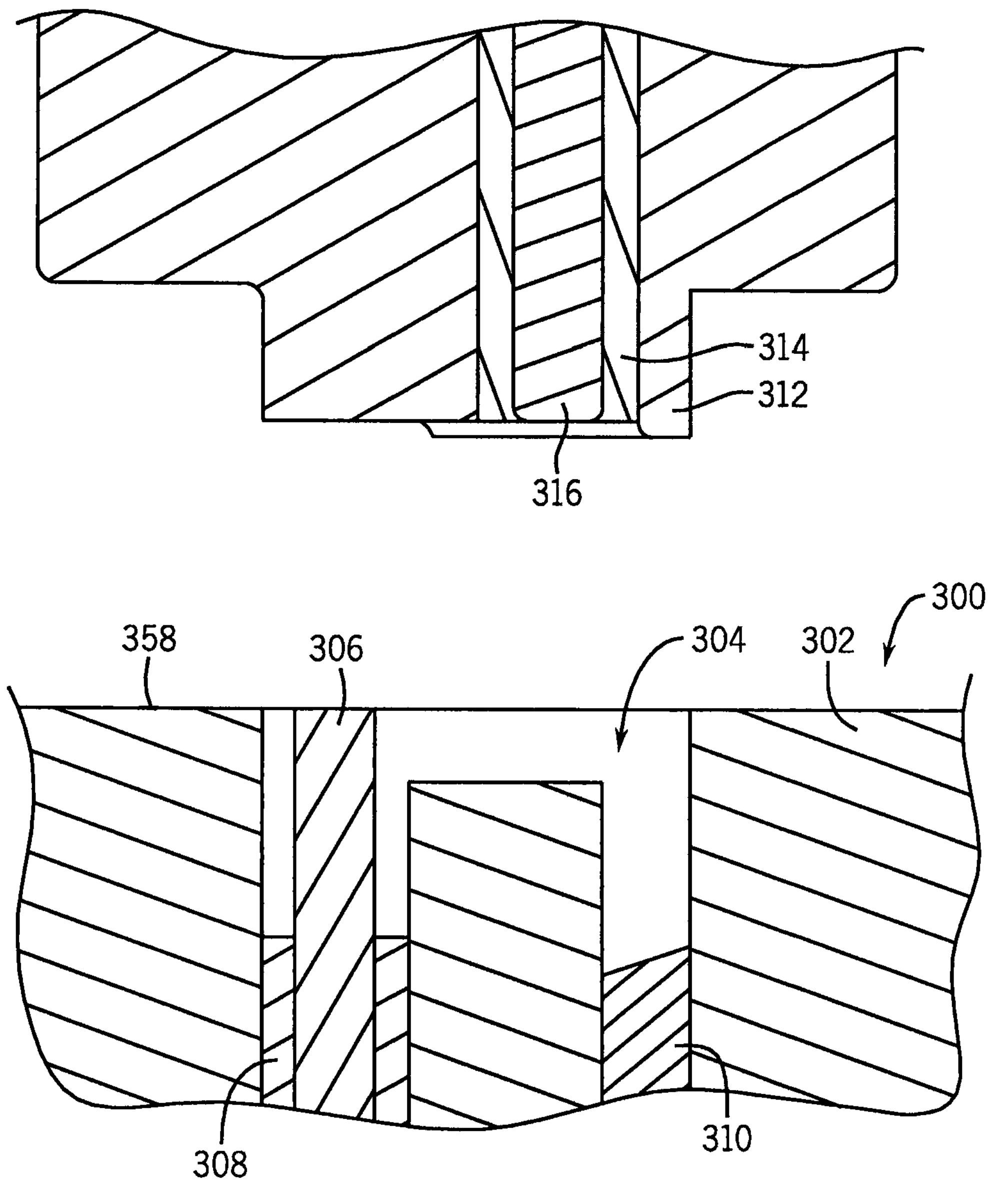


FIG. 6

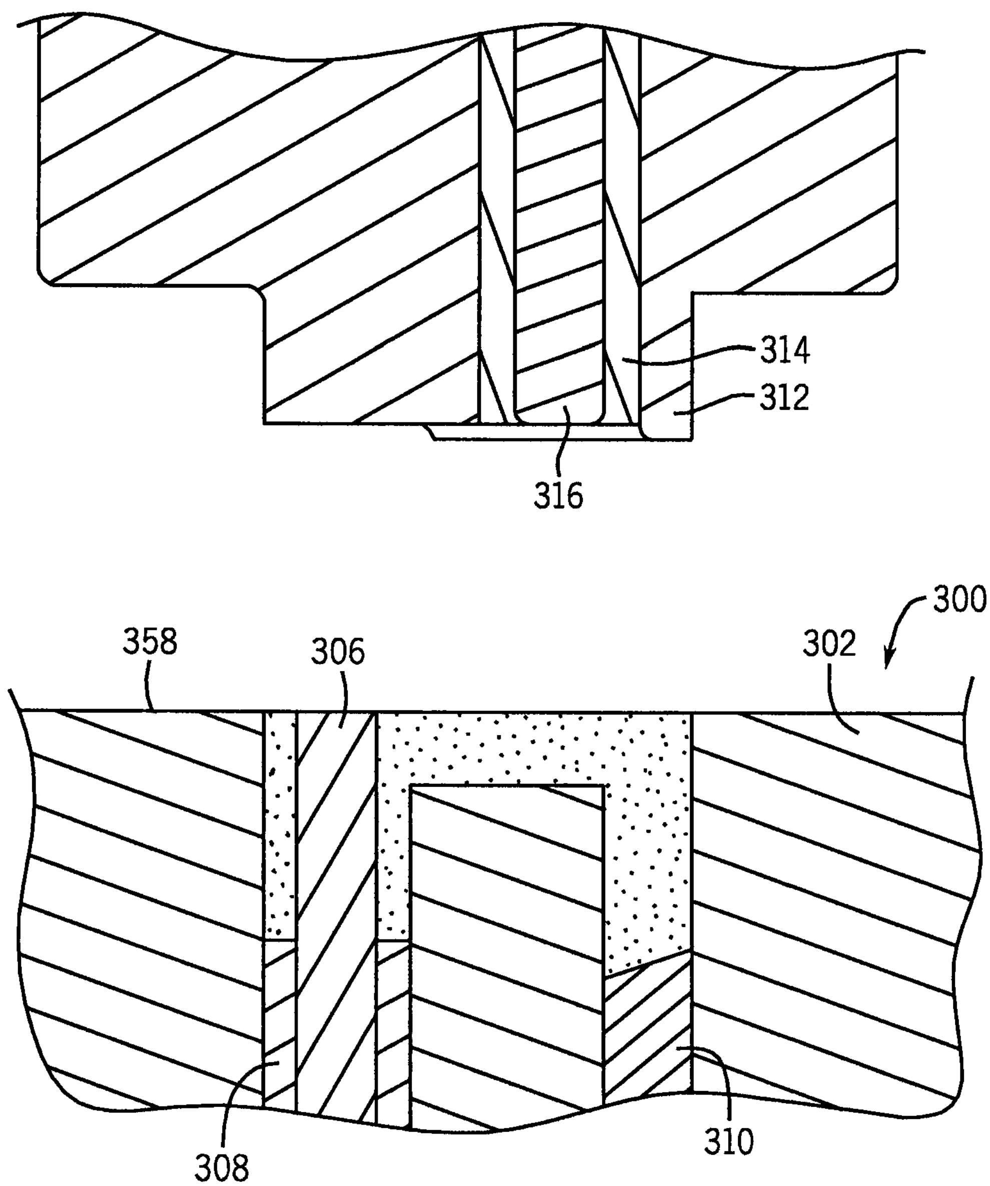


FIG. 7

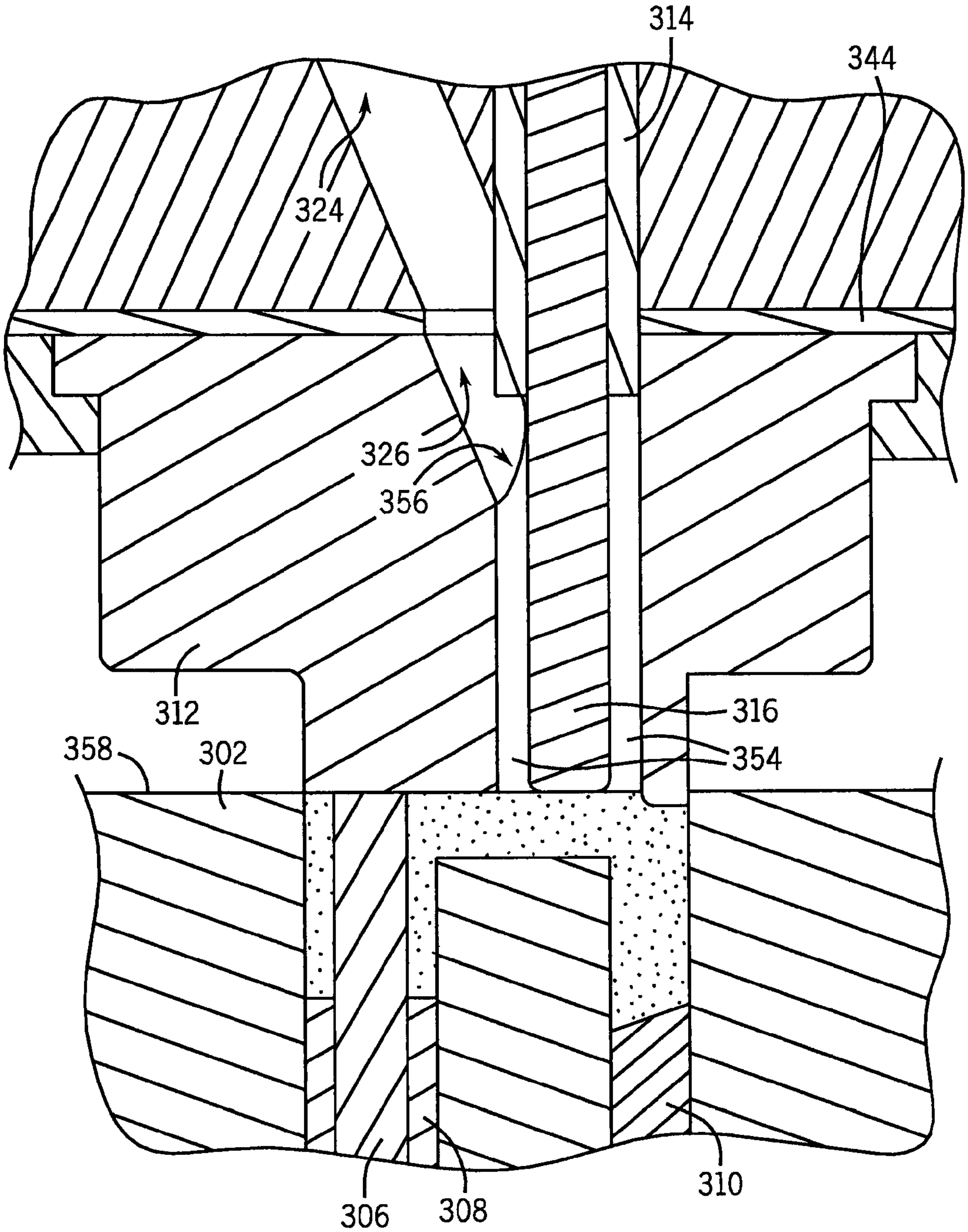


FIG. 8

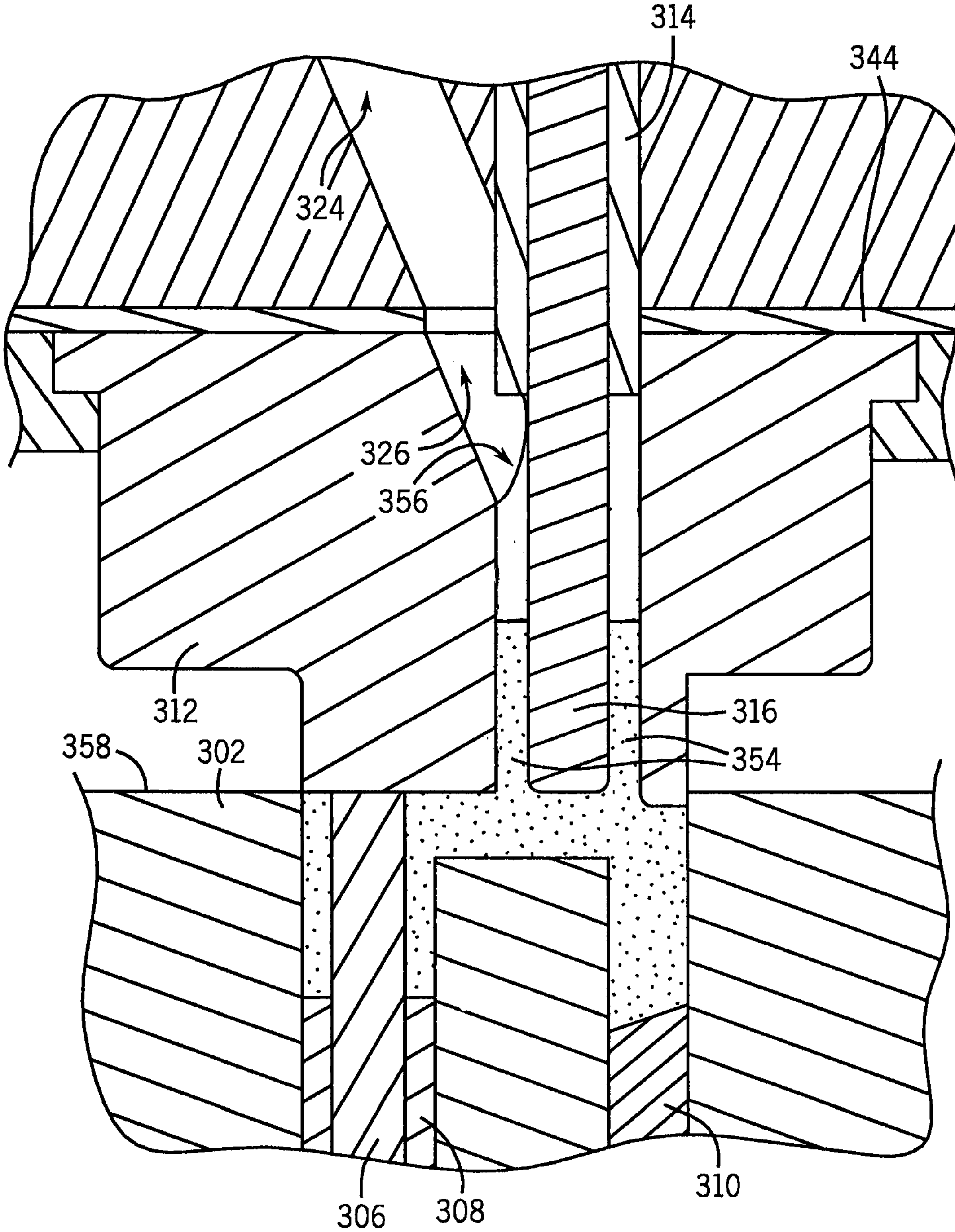


FIG. 9

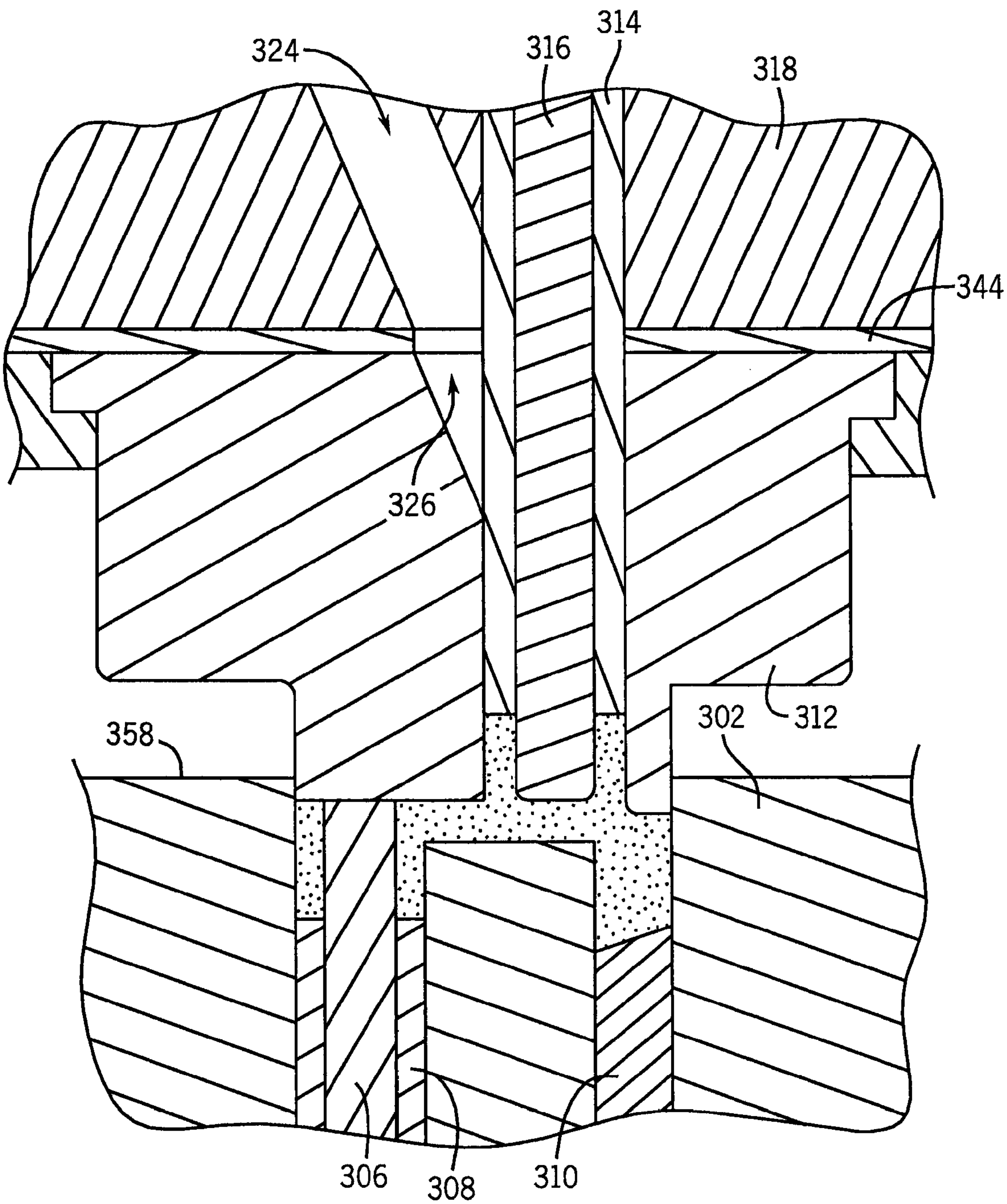


FIG. 10

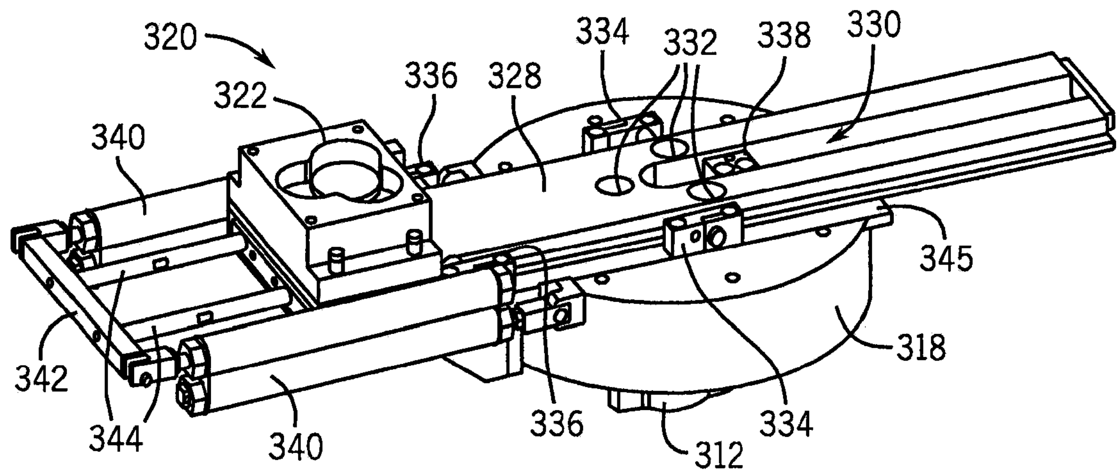

320
322
336
328
334
332
338
330
340
345
318
342
344
340
336
334
312

FIG. 11

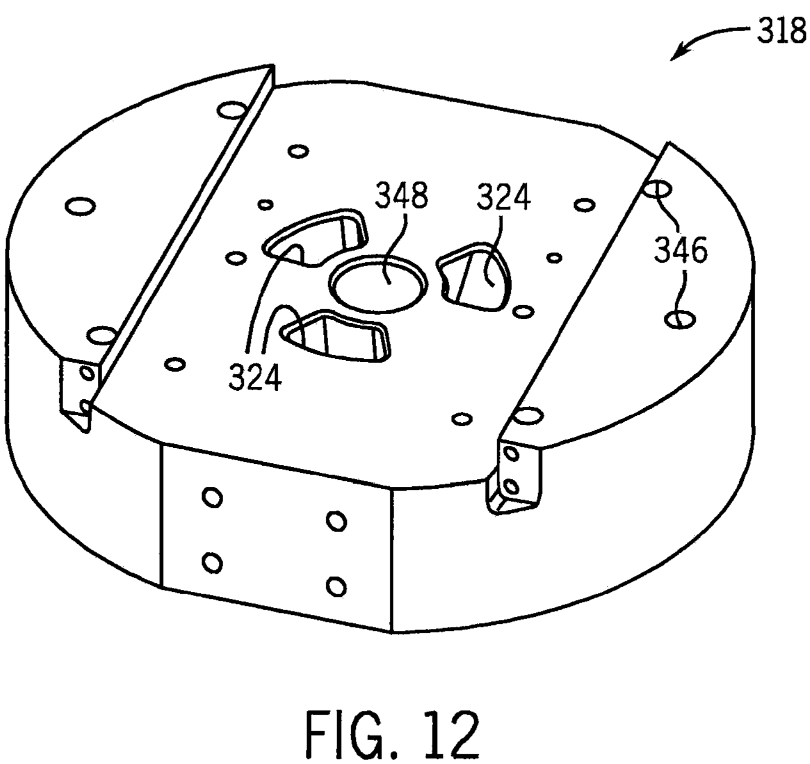

318
348
324
346
324

FIG. 12

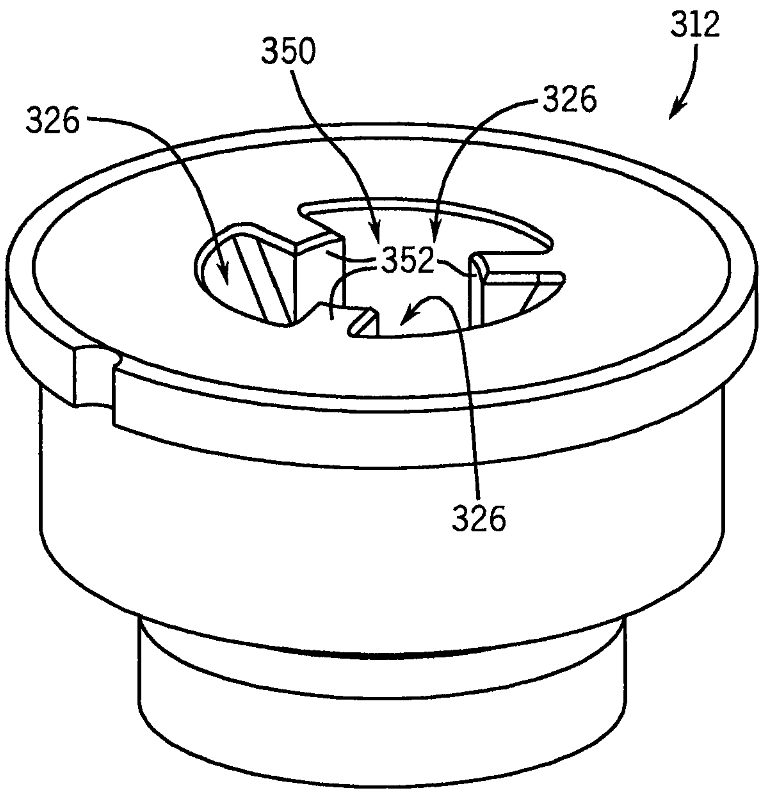


FIG. 13

POWDER METAL DIE FILLING

CROSS-REFERENCES TO RELATED APPLICATIONS

This application represents the national stage entry of PCT International Application No. PCT/US2010/035095 filed on May 17, 2010 and claims the benefit of U.S. provisional patent application No. 61/179,125 entitled "Powder Metal Die Filling" filed on May 18, 2009, and U.S. provisional patent application No. 61/225,799 entitled "Powder Metal Die Filling" filed on Jul. 15, 2009. The contents of both of these applications are hereby incorporated by referenced as if set forth in their entirety herein.

STATEMENT CONCERNING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not applicable.

BACKGROUND OF THE INVENTION

This invention relates to powder metal components and the process used to make them. In particular, this invention relates to a method of making parts having complex shapes using powder metal compaction.

Powder metallurgy provides a method of forming metallic parts. Making a part from powder metal typically includes the steps of filling a tool and die set with a powder metal powder, uni-axially compacting the metal powder using the tool and die set to form a powder metal compact, and sintering the powder metal compact to bond the particles of the powder metal compact together to form a final powder metal part. Although the final powder metal part is usually less than fully dense, a powder metal part has exceptional dimensional accuracy in comparison to parts made using other metal fabrication techniques.

To form the top side features in a powder metal compact, between the fill and compaction step, powder metal from the lower portion of the die is transferred upward by the relative movement of the lower tool members. If properly done, this powder transfer moves the powder to the appropriate location within the die cavity for compaction while simultaneously maintaining a powder fill to final part ratio of approximately 2:1 over the different vertical columns of the die cavity in the direction of compaction. If the powder fill to final part ratio is not maintained across the various features of the part, then the final part may have unacceptable variations in density.

Even though some parts having complex shapes can be made using powder metallurgy, certain geometries cannot be produced as a single part using the above-described techniques. To make powder metal parts having these geometries, two or more sections of the part need to be separately compacted and then joined together after compaction. However, two or more separate compaction steps and a joining step is time consuming, costly, and is likely to require significant post-sintering secondary operations.

Hence, a need exists for a way to form powder metal parts having complex geometries.

SUMMARY OF THE INVENTION

A method of forming a powder metal compact is disclosed. A tool set is utilized including a die having a die cavity, at least one lower tool member, and at least one upper tool member. At least one powder feed chute extends through one of the upper tool members. The lower tool member or members are inserted into the die cavity. The die cavity is filled with a powder metal in a first fill step. An upper tool member or members are then lowered to define a pre-compaction chamber. The pre-compaction chamber includes a filled section that was filled with the powder metal during the first fill step and an unfilled section that is not yet filled with the powder metal. The unfilled section of the pre-compaction chamber is filled with powder metal in a second fill step via the at least one powder feed chute that extends through the at least one upper tool member into the pre-compaction chamber. The powder metal is compacted along an axis of compaction to form a powder metal compact. The powder metal compact is then ejected from the die cavity.

The second fill step may include shuttling the powder metal from a hopper system to the upper tool member using a feed plate assembly. The feed plate assembly may include a sliding plate that has at least one powder cavity of a metered volume formed in the sliding plate. The sliding plate may be moveable between a first position and a second position. In the first position, the powder cavity or cavities are located beneath the hopper system to receive a charge of powder metal equal in volume to the powder cavity or cavities. In the second position, the powder cavity or cavities are placed in communication with the powder feed chute or chutes in the upper tool member to allow the charge of powder metal to be fed to the pre-compaction chamber.

There may also be a support block between the feed plate assembly and the upper tool member. The feed plate assembly may be positioned on a top side of the support block and the upper tool member may be attached to a bottom side of the support block. The support block may include at least one powder feed chute that places the powder cavity or cavities of the sliding plate in communication with the powder feed chute or chutes of the upper tool member when the sliding plate is in the second position.

The sliding plate may include a slot through which other upper tool member or members extend in both the first position and the second position of the sliding plate. The sliding plate may have a plurality of powder cavities that are not co-axial with the upper tool member or members that extend through the slot in the sliding plate.

The powder feed chute or chutes in the upper tool member may extend through the upper tool member at an angle relative to the axis of compaction.

The tool set may include an upper inner punch, an upper middle punch surrounding at least a portion of the upper inner punch, and an upper outer punch surrounding at least a portion of the upper middle punch. The step of lowering the upper tool member or members to define the pre-compaction chamber may include lowering the upper outer punch. The step of lowering the upper tool member or members to define the pre-compaction chamber may further include lowering the upper inner punch to form a cylindrical cavity or the like over the die cavity. During the second fill step, the upper middle punch may be in a retracted position to place the powder feed chute or chutes of the upper outer punch in communication with the pre-compaction chamber. During the step of compacting the powder metal, the upper middle punch may be lowered such that a surface of the upper middle punch slides past an opening of the powder feed chute or chutes in the upper outer punch to remove the powder feed chute or chutes from communication with the pre-compaction chamber.

The powder metal compact formed by the method may have at least two different cross sections taken perpendicular to the axis of compaction of the powder metal compact. Each of the two cross sections may have a first filled powder area that is not included in the other of the cross sections. Each of the two cross sections may also have a second filled powder area that is included in the other of the cross sections. This part geometry may be achieved using a top fill during the second fill step and not by a conventional powder transfer motion of the lower tool member or members. A ratio of a powder fill to a final powder metal compact may be approximately 2:1 across the various vertical columns of the die cavity.

The first fill step may be performed by placing a feed shoe over the die cavity.

The second fill step may be performed by gravity.

The step of lowering the upper tool member or members to define a pre-compaction chamber may include moving a lower surface or surfaces of the upper tool member or members flush with a powder metal fill surface of the powder metal from the first fill step.

The method may further include the step of sintering the powder metal compact to form a sintered powder metal part. Thus, a sintered powder metal part made by the method is also disclosed.

Likewise, a powder metal compact made by the method is disclosed. As stated above, the powder metal compact may have at least two different cross sections taken perpendicular to the axis of compaction of the powder metal compact. Each of the different cross sections have a first filled area of powder metal that is included in the other of the different cross sections and a second filled area of powder metal that is not included in the other of the different cross sections.

Thus, the disclosed method provides a way to fabricate a powder metal compact using a top fill step through one or more of the upper tool members. The top fill step allows for pre-compaction chamber, formed at least in part by the upper tool members, to be filled with a powder metal in a manner that is not possible using conventional lower tool powder transfer motions without complex lower tooling members. Further, the manner in which the pre-compaction chamber is filled avoids unacceptable variations in powder fill to final part ratios across the powder metal compact.

These and still other advantages of the invention will be apparent from the detailed description and drawings. What follows is merely a description of some preferred embodiments of the present invention. To assess the full scope of the invention, the claims should be looked to as these preferred embodiments are not intended to be the only embodiments within the scope of the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a top perspective view of a segment gear showing a hub side of the gear;

FIG. **2** is a bottom perspective view of the segment gear of FIG. **1** showing the axially-facing gear teeth;

FIG. **3** is a top plan view of the segment gear of FIG. **1**;

FIG. **4** is a cross-sectional side view of the segment gear taken along line **4-4** of FIG. **3**;

FIG. **5** is a flow chart outlining a set of steps for the fabrication of a complex part such as the segment gear;

FIGS. **6-10** are cross-sectional views of a tool and die set in a compaction press in which the upper and lower tool members are in the first fill position before the first fill, the first fill position after the first fill, the second fill position after the upper tool members have been lowered but before the second fill, the second fill position after the second fill, and the compaction position, respectively;

FIG. **11** is a perspective view of a feed plate assembly attached to a support block;

FIG. **12** is a top perspective view of a support block without the feed plate assembly or the upper outer punch attached; and

FIG. **13** is a top perspective view of the upper outer punch.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring first to FIGS. **1-4**, a one piece segment gear **100** is shown. The segment gear **100** is fabricated as a single powder metal compact using the powder metal processes according to a process **200** described below. However, the structure of the segment gear **100** is now described to provide context for the steps of the process **200**.

The segment gear **100** is a powder metal part which is formed by compression along an axis of compaction which is parallel to axis A-A and B-B. The segment gear **100** includes a pie-shaped body section **102** having a top surface **104** and a bottom surface **106** which are generally parallel to one another and which are both perpendicular to axis A-A. The body section **102** extends from a central hub **108** at an axis A-A to an arcuate wall **110** at an outer periphery of the segment gear **100**.

The central hub **108** is generally cylindrically-shaped and extends downward from the bottom surface **106** of the body section **102**. The central hub **108** and has a lower axial surface **112**, a radially-outward facing surface **114**, and an axially-extending through hole **116** which extends from the top surface **104** to the lower axial surface **112**. The axially-extending through hole **116** has radially-inward facing splines **118** formed therein.

The arcuate wall **110** extends downward from the bottom surface **106** of the body section **102**. The arcuate wall **110** includes a radially-inward facing surface **120** and a radially-outward facing surface **122**. On the downward facing surface between the radially-inward facing surface **120** and the radially-outward facing surface **122** of the arcuate wall **110**, a plurality of gear teeth **124** are formed. In the form shown, the gear teeth **124** extend in a generally radially direction relative to axis A-A although the planes defining the tips of the gear teeth **124** are non-perpendicular to the axis A-A.

A top side hub **126** is formed on the top surface **104** of the body section **102** and extends along axis B-B which is parallel to, but spaced from, axis A-A. The top side hub **126** is generally cylindrically-shaped having a radially-outward facing surface **128**, a radially-inward facing surface **130**, and an upper axial surface **132**. The radially-inward facing surface **130** defines a cylindrically-shaped cavity **134** in the top side hub **126**. A lower surface **136** of the cavity **134** is essentially parallel with the top surface **104** of the body section **102**.

As best shown in FIGS. **1** and **4**, the top surface **104** also includes a step **138** proximate the arcuate wall **110**. The step **138** is offset from the rest of the top surface **104**. As the top side hub **126** straddles the step **138** and the rest of the top surface **104**, vertical columns of material having varying thicknesses are provided in the region of the top side hub **126** and the arcuate wall **110**.

It should be appreciated that a part having this geometry could not be formed as a unitary powder metal compact by a conventional powder metal compaction process. Typically, attempts to form top features, such as the hub **126**, are made by transferring powder metal within the die cavity by a powder transfer motion of the lower tool members. As the powder is transferred, the powder fill to final part ratio along the vertical columns of the part must be approximately 2:1 to provide a part that is relatively uniformly dense after the compaction process.

However, a comparison of a horizontal cross section through the hub **126** and a horizontal cross section through the arcuate wall **110** with gear teeth **124** would reveal that there are areas of powder metal in the hub **126** which are not found in the arcuate wall **110** with gear teeth **124** and areas of powder metal in the arcuate wall **110** with gear teeth **124** that are not found in the hub **126**. Thus, conventional tool and die sets are incapable of performing a powder transfer motion that provides an acceptable powder fill to final part ratio over a component having this final geometry. Instead, to fabricate a part of this type, the different sections are conventionally separately compacted and then joined afterwards.

Referring now to FIG. **5**, a process **200** is outlined that allows for the formation of a single powder metal compact, and ultimately a sintered powder metal part, for a component having a geometry similar to the segment gear **100**. With additional reference to FIGS. **6-10**, which show specific steps of the filling and compaction steps, the steps of the process **200** will be described.

In order to form the powder metal compact, a tool and die set must be provided and installed in a compaction press. As shown in FIGS. **6-10**, the tool and die set includes a die **300** having a die insert **302** that defines a portion of the die cavity **304**. The die insert **302** is typically made of a hard tool material and is formed to have a shape similar to the outline of the periphery of the part. The lower tool members includes a lower core rod **306** which forms the through hole **116**, a lower outer punch **308** surrounding the lower core rod **306** which forms the lower axial surface **112**, and a lower tool member **310** which form the gear teeth **124**. The lower tool members are inserted upward into the die cavity **304** so as to provide a bottom floor in the die cavity **304** and to provide side walls in locations which the die insert **302** would be incapable of forming side walls during compaction (e.g., the radially outward facing surfaces of the lower core rod **306** to form the splines **118** of the through hole **116**). A number of upper tool members are also provided including an upper outer punch **312** sized to fit into a periphery of an upper portion of the die cavity **304**, an upper middle punch **314** that is at least in part surrounded by the upper outer punch **312**, and an upper inner punch **316** that is at least in part surrounded by the upper middle punch **314**.

The upper tool members are configured such that a powder metal can be fed through at least one of the upper tool members. Referring now to FIGS. **11-13**, a support block **318** is shown to which the upper outer punch **312** and a feed plate assembly **320** are attached. The support block **318** is mounted to a portion of the upper press assembly such that the support block **318**, the upper outer punch **312**, and the feed plate assembly **320** move together regardless of the positioning of the other upper tool members.

The feed plate assembly **320** shuttles charges of the powder metal from an axially offset hopper system **322** to powder feed chutes **324** and **326** that run through the support block **318** and the upper outer punch **312**, respectively. The feed plate assembly **320** includes a sliding plate **328** that has a guide slot **330** and three powder cavities **332** which extend through the sliding plate **328**. The linear path of the sliding plate **328** is guided by a track system that slidably connects sliding plate **328** to the support block **318**. The track system includes front guides **334** and rear guides **336** that engage the lateral sides of the sliding plate **328** and a middle guide **338** that engages the walls of the guide slot **330**.

The feed plate assembly **320** includes an actuation mechanism that moves the three powder cavities **332** of the sliding plate **328** back and forth between the hopper system **322** and the powder feed chutes **324** and **326**. In the form shown, the actuation mechanism includes a set of cylinders **340** (shown retracted in FIG. **11**), which can be extended and retracted to move a connecting bar **342** that is connected to the sliding plate **328** via a pair of linkages **344**. Of course, other actuation mechanisms could be used to move the sliding plate **328**. As will be described in more detail below, the particular timing of the shuttling of the powder metal from the hopper system **322** to the powder feed chutes **324** and **326** is timed with the press cycle.

The track system and actuation mechanism allows the sliding plate **328** to be movable between a first position (not shown) and a second position (shown in FIG. **11**). In the first position, the powder cavities **332** are located under the hopper system **322** to receive a charge of powder metal. In the second position, the powder cavities **332** are slid over the support block **318** such that the bottom of the powder cavities **332** align with the upper openings of the powder feed chutes **324** in the support block **318** and are placed in communication with the powder feed chutes **324** and **326** of the support block **318** and upper outer punch **312**, respectively. When the powder cavities **332** are in any position other than over the powder feed chutes **324** in the support block **318**, a lower surface beneath the powder cavities **332** supplied by a support plate **345** (which also has holes aligning with the powder feed chutes **324**) prevents the powder metal charge from dropping out of the bottom of the powder cavities **332**.

Referring now to FIG. **12**, the details of the support block **318** are shown. The support block **318** is generally cylindrically shaped with a number of bolt holes **346** for mounting the support block **318** to the upper press assembly. A number holes and/or chutes extend through the support block **318**. A through hole **348** axially extends through the support block **318** to accommodate for the passage of the upper middle punch **314** and the upper inner punch **316** through the support block **318**. Additionally, three powder feed chutes **324** or channels are situated about the through hole **348**. As can be best seen in FIGS. **8** through **10**, the three powder feed chutes **324** extend axially inward as the powder feed chutes **324** extend downward.

Referring now to FIG. **13**, the details of the upper outer punch **312** are shown. The upper outer punch **312** has an opening **350** extending axially there through. When the upper outer punch **312** is mounted to the support block **318**, the opening **350** has three powder feed chutes **326** which align with the exit ends of the three powder feed chutes **324** on the bottom face of the support block **318**. These powder feed chutes **326** direct the powder metal downward and axially inward. Further, three walls **352** separate the feed chutes **326** from one another and guide the upper middle punch **314** (which has a complementary sliding fit with the inner diameter of the opening **350** as provided by the three walls **352**) as the upper middle punch **314** extends through the upper outer punch **312**.

Looking at the feed plate assembly **320**, the support block **318**, and the upper outer punch **312** in combination with the rest of the upper tool members, it should be observed that the particular design of the sliding plate **328** and powder feed chutes **324** and **326** is made to accommodate the extension of the upper middle punch **314** and the upper inner punch **316** through the other components. The slot **330** in the sliding plate **328**, the through hole **348** in the support block **318**, and the opening **350** of the upper outer punch **312** accommodate the passage and axial movement of the upper middle punch **314** and the upper inner punch **316** there through during the press cycle.

The movement of the upper middle punch **314** relative to the upper outer punch **312**, allows openings **356** of the powder feed chutes **326** to be opened or closed by sliding a radially outward facing surface of the upper middle punch **314** past the openings **356** in the upper outer punch **312**. The position of the powder cavities **332**, and the powder feed chutes **324** and **326** that align with the powder cavities **332** in the second position, are designed to provide a relatively even distribution of powder metal through the upper tooling members into the annular chamber **354**, when the upper middle punch **314** is sufficiently retracted, as will be described in more detail below.

The rest of the press and tool members will not be described in detail. However, those of ordinary skill in the art will appreciate that the press can be configured such that the stroke of each of the tool members relative to the die **300** can be controlled independently. Further, those having ordinary skill in the art will appreciate that other combinations of tool members could be substituted to perform similar functions. For example, the upper outer punch **312** could be replaced by two separate punches including a punch used to form the step **138** separate from the rest of the top surface **104**. Likewise one or more lower tool members may be used to form the gear teeth **124**.

Referring now to FIG. **6**, the filling and compaction steps begin with the lower core rod **306**, lower outer punch **308**, and lower tool member **310** being inserted in the die cavity **304** from below to form a bottom of the die cavity **304** and additional interior side walls. Although the lower tool members provides a base or floor of the die cavity **304**, the lower tools are also retracted relative to their compaction position which is illustrated in FIG. **10**. Prior to the powder filling, all of the upper tool members are initially in a lifted position above the die cavity **304**.

With the upper tool members lifted as shown in FIG. **6**, a feed shoe (not shown) can be moved over the die cavity **304** to fill the die cavity **304** with a powder metal according to the first fill step **202**. When the feed shoe is retracted from over the die cavity **304**, the powder metal fill line in the die cavity **304** is level with an upper surface **358** of the die **300** as illustrated in FIG. **7**.

Next, at least some of the upper tool members are lowered towards the die cavity **304** according to step **204**. As shown in FIG. **8**, the upper outer punch **312** and the upper inner punch **316** are lowered to a point at which their lower axial faces are flush with (or slightly below) the powder metal fill line which corresponds to the upper surface **358** of the die **300**. The upper outer punch **312** and the upper inner punch **316** may be brought into contact with the powder metal already in the die cavity **304** from the first fill step **202**, but do not significantly compact the powder metal at this point in the process.

It is observed that the axial face of the upper outer punch **312** used to form the step **138** is slightly below the powder metal fill line in FIG. **8**. Depending on the particular dimensions and compactability of powder metal, this slight compaction of the powder metal below the face of the upper outer punch **312** may be acceptable. However, if this slight compaction is not acceptable, then this condition may be remedied by replacing the one-piece upper outer punch with a two-piece upper outer punch having one piece that moves independently of the other piece that forms the step **138**.

At some point, either before or after the upper tool members are lowered, the upper middle punch **314** is retracted relative to the upper outer punch **312** and the upper inner punch **316**. This defines an annularly-shaped cylindrical space **354** between the upper outer punch **312** and the upper inner punch **316** that will be used to form the top side hub **126**. It should be noted, however, that the timing and degree of the retraction of the upper middle punch **314** needs to be properly coordinated with the delivery of the powder metal charge by the feed plate assembly **320**. When the upper middle punch **314** is retracted above the powder feed chutes **326** of the opening **350** in the upper outer punch **312**, if powder is present in the powder feed chutes **326**, the powder will be delivered by gravity into the space **354** between the upper outer punch **312** and the upper inner punch **316**. If the upper tool members are not yet descended to a position such as that shown in FIG. **8**, then the powder metal will be prematurely fed and not captured in the annularly-shaped cylindrical space **354**.

When the upper tool members are lowered into the position shown in FIG. **8**, the upper tool members, the lower tool members, and the die cavity define a pre-compaction chamber. The pre-compaction chamber includes a filled portion, which includes the bottom portion previously filled with powder metal during the first fill step **202**, and an unfilled portion, which is the volume defined by the space **354** between the upper tool members above the powder metal fill line from the first fill step **202**.

At this point, the powder metal from the upper tooling members is delivered to the unfilled portion of the pre-compaction chamber in a second fill step **206**. This delivery is performed by shuttling powder metal via the powder cavities **332** of the sliding plate **328** from the hopper system **322** to the powder feed chutes **324** in the support block **318**. Once the powder cavities **332** are aligned with the powder feed chutes **324** in the support block **318**, gravity causes the powder metal in the powder cavities **332** to drop through the powder feed chutes **324** in the support block **318**, through the powder feed chutes **326** in the upper outer punch **312**, and into the annular space **354** (assuming the upper middle punch **314** is sufficiently retracted to place the powder feed chutes **326** in communication with the annular space **354**). The charge of powder metal delivered to the unfilled portion of the pre-compaction chamber should provide an appropriate amount of powder metal to the unfilled portion of the pre-compaction chamber to form the top side hub **126**. As the powder cavities **332** are of metered volume, the aggregate metered volume can be selected to be of a volume equal to the amount of powder metal to form the top side hub **126**. Although only one set of powder feed chutes **324** and **326** are shown in the cross section of FIG. **8**, as can be appreciated from FIGS. **11**-**13**, there are, in fact, three powder feed chutes. Depending on the particular design of the tools there may be one or more powder feed chutes within the upper tool members.

Once the second fill step **206** is complete as is illustrated in FIG. **9**, then the powder fill to final part ratio should be approximately 2:1 in each of the vertical columns of powder. Of course, as some powder materials have different compressibilities or targeted compacted apparent densities, and so the exact ratio may differ.

After the second fill step **206**, the powder metal is properly distributed within the pre-compaction chamber formed by the tool members and the die. Now the upper middle punch **314** is lowered to seal the openings **356** of the powder feed chutes **326**, completely closing the pre-compaction chamber. At this point, the upper and lower tool members can compress the powder metal in the pre-compaction chamber according to the compaction step **208**. The final tool placement at the end of the compaction step **208** is shown in FIG. **10**. During compaction, the upper outer punch **312** and the upper inner punch **316** are moved downward into the die insert **302** to form the body section **102**, the upper middle punch **314** is moved downward to form the top side hub **126**, the lower outer punch **308** is extended upward to form the central hub **108**, and the lower tool member **310** is moved upward to form the gear teeth **124**. This forms a one piece powder metal compact having a geometry of the segment gear **100**.

After the powder metal compact is formed, the powder metal compact is ejected from the tools and die in an ejection step **210**. During ejection, the upper and lower tool members are retracted in a coordinated sequence to separate the powder metal compact from the surfaces of the upper and lower tools and die. Typically, the upper outer punch **312** and upper inner punch **316** would be retracted first, while the upper middle punch **314** held the upper axial surface **132** of the top side hub **126** in place to prevent the compacted top side hub **126** from fracturing due to upward force on the radially-facing walls. Once the upper tool members are removed from the powder metal compact, the lower tools are raised to an eject position in which the bottom side features are ejected from the walls of the die cavity **304**. Of course, the ejection sequence may vary based on part geometry and the die and tool members used to form the powder metal compact.

Finally, the powder metal compact may be sintered according to step **212**, by processes well known in the art. During sintering, the powder metal compact is heated to temperatures below the melting point of the powder metal in a controlled atmosphere to cause the powder metal particles to diffuse, resulting in the particles necking together, and forming a strong solid sintered part. During sintering the part dimensions may shrink as porosity decreases, but the part maintains its general shape. To account for this shrinkage, the powder metal compact is typically engineered to be slightly larger than the final sintered part.

Additionally, the sintered part may be subjected to any number of finishing or secondary process. The sintered part could be deburred, machined, heat treated, carburized, coined, forged, or subjected to any of a number other post-sintering operations known to those of ordinary skill in the art.

Although a method has been disclosed to create a segment gear having a hub on the top and a central hub and axially-oriented gear teeth on the bottom, the disclosed method is applicable to any part having asymmetric top and bottom features in which lower tool members are incapable of performing a powder transfer motion necessary to achieve sufficient powder fill to final part ratios.

It should also be noted that various spacer plates may be incorporated in the tool design and press set up. To the extent necessary, such spacer plates or other support blocks may also be formed to include holes or powder feed chutes to allow for the delivery of powder through the upper tool members.

It should further be appreciated that the powder feed chute need not necessarily extend to the lowest upper tool member. For example, the powder feed chute opening which places the chute in communication with the pre-compaction chamber could be formed in the support block **318**, although in the tool setup shown, this would require lifting the upper middle punch **314** past this opening during the top fill step. It will be appreciated that one having skill in the art would recognize that this and other such modifications to the tool set could be made to achieve the same top fill capability.

It should be appreciated that various other modifications and variations to the preferred embodiments can be made within the spirit and scope of the invention. Therefore, the invention should not be limited to the described embodiments. To ascertain the full scope of the invention, the following claims should be referenced.

What is claimed is:

1. A method of forming a powder metal compact using a tool set including a die having a die cavity, at least one lower tool member, and at least one upper tool member, the method comprising:

inserting the at least one lower tool member into the die cavity;

filling the die cavity with a powder metal in a first fill step;

lowering the at least one upper tool member to define a pre-compaction chamber, the pre-compaction chamber including a filled section that was filled with the powder metal during the first fill step and an unfilled section that is not yet filled with the powder metal;

filling the unfilled section of the pre-compaction chamber with powder metal in a second fill step via at least one powder feed chute that extends through the at least one upper tool member into the pre-compaction chamber;

compacting the powder metal along an axis of compaction to form a powder metal compact; and

ejecting the powder metal compact from the die cavity;

wherein the second fill step includes shuttling the powder metal from a hopper system to the at least one powder feed chute in the at least one upper tool member using a feed plate assembly including a sliding plate having at least one powder cavity of a metered volume formed therein, the sliding plate being moveable between a first position in which the at least one powder cavity is located beneath the hopper system to receive a charge of powder metal equal in volume to the at least one powder cavity and a second position in which the at least one powder cavity is placed in communication with the at least one powder feed chute in the at least one upper tool member to allow the charge of powder metal to be fed to the pre-compaction chamber.

2. A method of claim **1**, further comprising a support block having the feed plate assembly positioned on a top side thereof and an upper tool member attached to a bottom side thereof and wherein the support block includes at least one powder feed chute that places the at least one powder cavity of the sliding plate in communication with the at least one powder feed chute of the upper tool member when the sliding plate is in the second position.

3. A method of claim **1**, wherein the sliding plate includes a slot through which at least one upper tool member extends in both the first position and the second position of the sliding plate.

4. A method of claim **3**, wherein the sliding plate includes a plurality of powder cavities and the plurality of powder cavities are not co-axial with the at least one upper tool member that extends through the slot in the sliding plate.

5. A method of forming a powder metal compact using a tool set including a die having a die cavity, at least one lower tool member, and at least one upper tool member, the method comprising:

inserting the at least one lower tool member into the die cavity;

filling the die cavity with a powder metal in a first fill step;

lowering the at least one upper tool member to define a pre-compaction chamber, the pre-compaction chamber including a filled section that was filled with the powder metal during the first fill step and an unfilled section that is not yet filled with the powder metal;

filling the unfilled section of the pre-compaction chamber with powder metal in a second fill step via at least one powder feed chute that extends through the at least one upper tool member into the pre-compaction chamber;

compacting the powder metal along an axis of compaction to form a powder metal compact; and

ejecting the powder metal compact from the die cavity;

wherein the tool set includes an upper inner punch, an upper middle punch surrounding at least a portion of the upper inner punch, and an upper outer punch surrounding at least a portion of the upper middle punch.

6. A method of claim **5**, wherein the at least one powder feed chute in the at least one upper tool member extends through the at least one upper tool member at an angle relative to the axis of compaction.

7. A method of claim **5**, wherein the step of lowering the at least one upper tool member to define the pre-compaction chamber includes lowering the upper outer punch.

8. A method of claim **7**, wherein the step of lowering the at least one upper tool member to define the pre-compaction chamber further includes lowering the upper inner punch.

9. A method of claim **7**, wherein, during the second fill step, the upper middle punch is in a retracted position to place the at least one powder feed chute of the upper outer punch in communication with the pre-compaction chamber and wherein, during the step of compacting the powder metal, the upper middle punch is lowered such that a surface of the upper middle punch slides past an opening of the at least one powder feed chute to remove the powder feed chute from communication with the pre-compaction chamber.

10. A method of forming a powder metal compact using a tool set including a die having a die cavity, at least one lower tool member, and at least one upper tool member, the method comprising:

inserting the at least one lower tool member into the die cavity;

filling the die cavity with a powder metal in a first fill step;

lowering the at least one upper tool member to define a pre-compaction chamber, the pre-compaction chamber including a filled section that was filled with the powder metal during the first fill step and an unfilled section that is not yet filled with the powder metal;

filling the unfilled section of the pre-compaction chamber with powder metal in a second fill step via at least one powder feed chute that extends through the at least one upper tool member into the pre-compaction chamber;

compacting the powder metal along an axis of compaction to form a powder metal compact; and

ejecting the powder metal compact from the die cavity;

wherein the powder metal compact has at least two different cross sections taken perpendicular to the axis of compaction of the powder metal compact and wherein each of the at least two different cross sections have a first filled powder area that is not included in the other of the at least two different cross sections and a second filled powder area that is included in the other of the at least two different cross sections;

wherein a top fill on the powder metal compact is achieved by the second fill step and not by a powder transfer motion of the at least one lower tool member.

11. A method of claim **10**, wherein the first fill step is performed by placing a feed shoe over the die cavity and wherein a powder metal fill line in the die cavity is level with an upper surface of the die.

12. A method of claim **10**, wherein the second fill step is performed by gravity.

13. A method of claim **10**, wherein the step of lowering the at least one upper tool member to define a pre-compaction chamber includes moving a lower surface of the at least one upper tool member flush with a powder metal fill surface of the powder metal from the first fill step.

14. A method of claim **10**, wherein a ratio of a powder fill to a final powder metal compact is approximately 2:1.

15. A method of claim **10**, further comprising the step of sintering the powder metal compact to form a sintered powder metal part.

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